ANALOG DEVICES

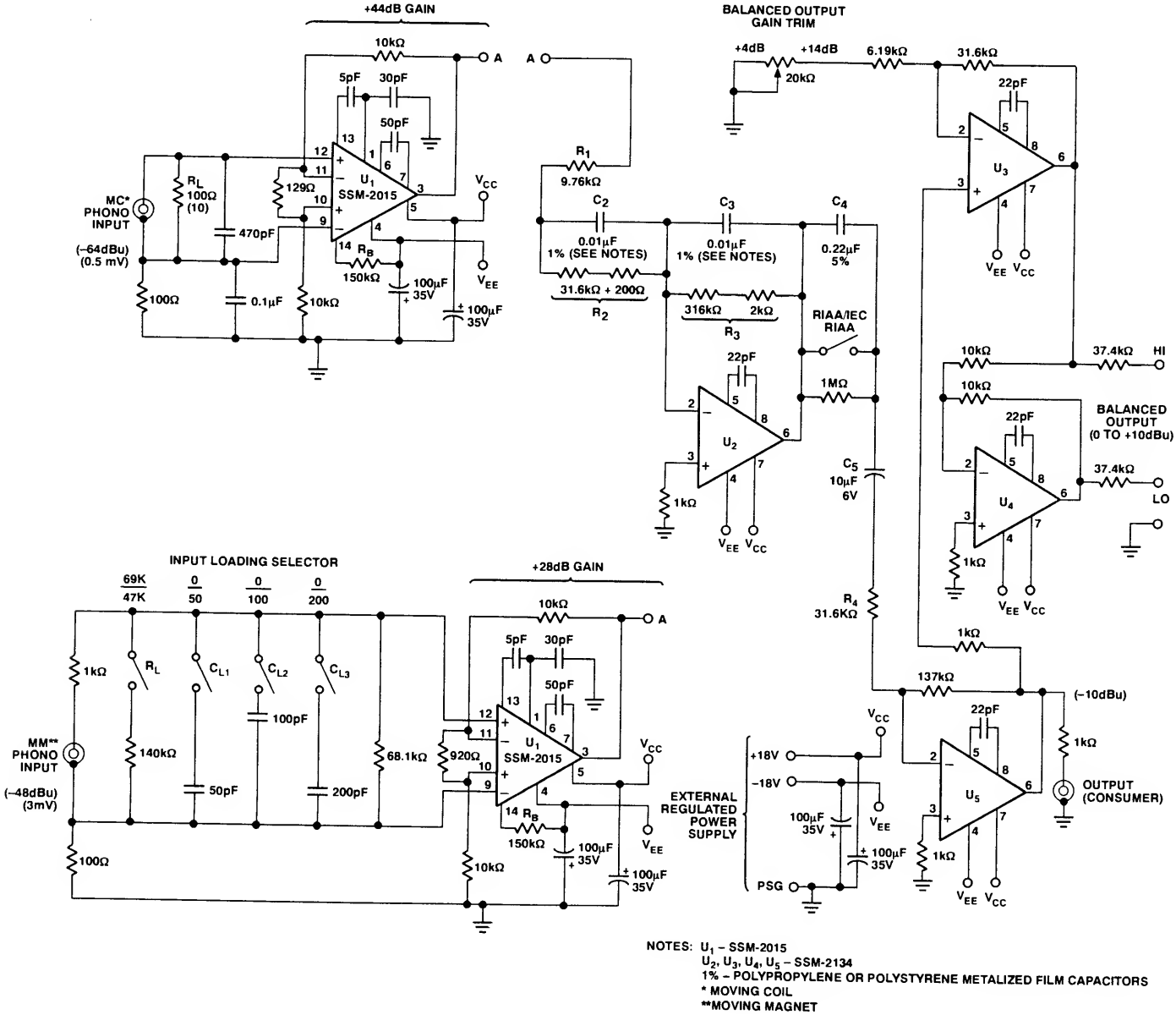
AN-124
APPLICATION NOTE

ONE TECHNOLOGY WAY • P.O. BOX 9106 • NORWOOD, MASSACHUSETTS 02062-9106 • 617/329-4700

Three High Accuracy RIAA/IEC MC and MM Phono Preamplifiers

Although the digital compact disk is rapidly supplanting the vinyl disk as the popular media method for professional and consumer audio entertainment, the electro-mechanical recording and reproduction of audio signals has many more years of life. The group of phono preamplifier application designs below will make the future years with vinyl more productive and pleasant. The applications employ solid engineering concepts, and dismiss "golden ear" discussions.

One design includes an input scheme for both moving coil (MC) and moving magnet (MM) – or variable reluctance – transducers. All designs employ extremely low noise circuit topologies, high accuracy active and passive RIAA (Recording Industries Association of America) equalization with selectable old RIAA or RIAA/IEC (International Electro-Technical Commission) curves. The applications incorporate both consumer and balanced output circuit configurations.



NOTES: U_1 – SSM-2015
U_2, U_3, U_4, U_5 – SSM-2134
1% – POLYPROPYLENE OR POLYSTYRENE METALIZED FILM CAPACITORS
* MOVING COIL
**MOVING MAGNET

FIGURE 1: *High Accuracy RIAA/IEC MC or MM Phono Preamplifier*

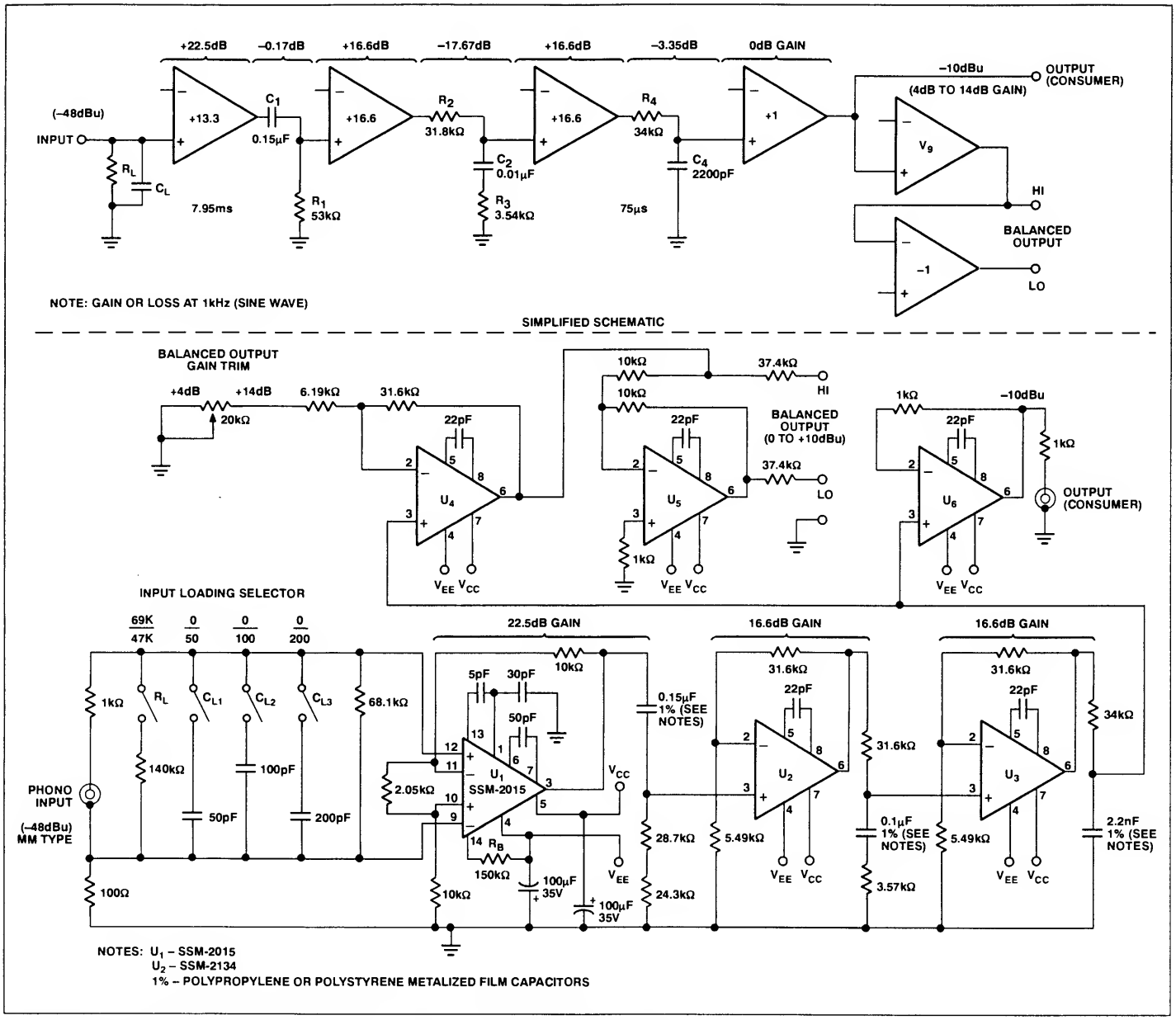


FIGURE 2: *Passive (Multi-Filter) RIAA/IEC Equalized Phono Preamplifier*

A HIGH ACCURACY DESIGN

In the High Accuracy RIAA/IEC Phono Preamplifier shown in Figure 1, both MC and MM transducer input configurations are presented. Both utilize the PMI SSM-2015 differential amplifier and take advantage of the high common-mode rejection it provides. The overall circuit structure *does not* incorporate any design compromises. It provides the lowest possible noise, adjustable MM input loading, highest accuracy RIAA filtering, and is completely devoid of transient and frequency dependent gain errors. The wide bandwidth stages minimize in-band phase shift, and provide exceptional phase and frequency response accuracy. This allows the RIAA/IEC filter to render the exact reciprocal of the recorded phase and frequency characteristics.

Referring to Figure 1, the MC input circuit has input loading (R_L) set at 100Ω. (Note: some MC transducers require 10Ω loading for maximum reproduction accuracy. For these, replace R_L with a 10Ω metal film resistor.) The input circuit gain is 44dB, and provides a −20dBu signal level at point A. 44dB gain should be adequate for most MC cartridges available. If U_1 gain requires adjusting, use the equation:

$$G_{dB} = 20 \log\left(3.5 + \frac{20 \times 10^3}{R_G}\right)$$

R_B sets the U_1 bias value and contributes to symmetrical amplifier slewing. The RIAA filter stage that follows U_1 stage(s) all but eliminates noise produced by the input amplifier.

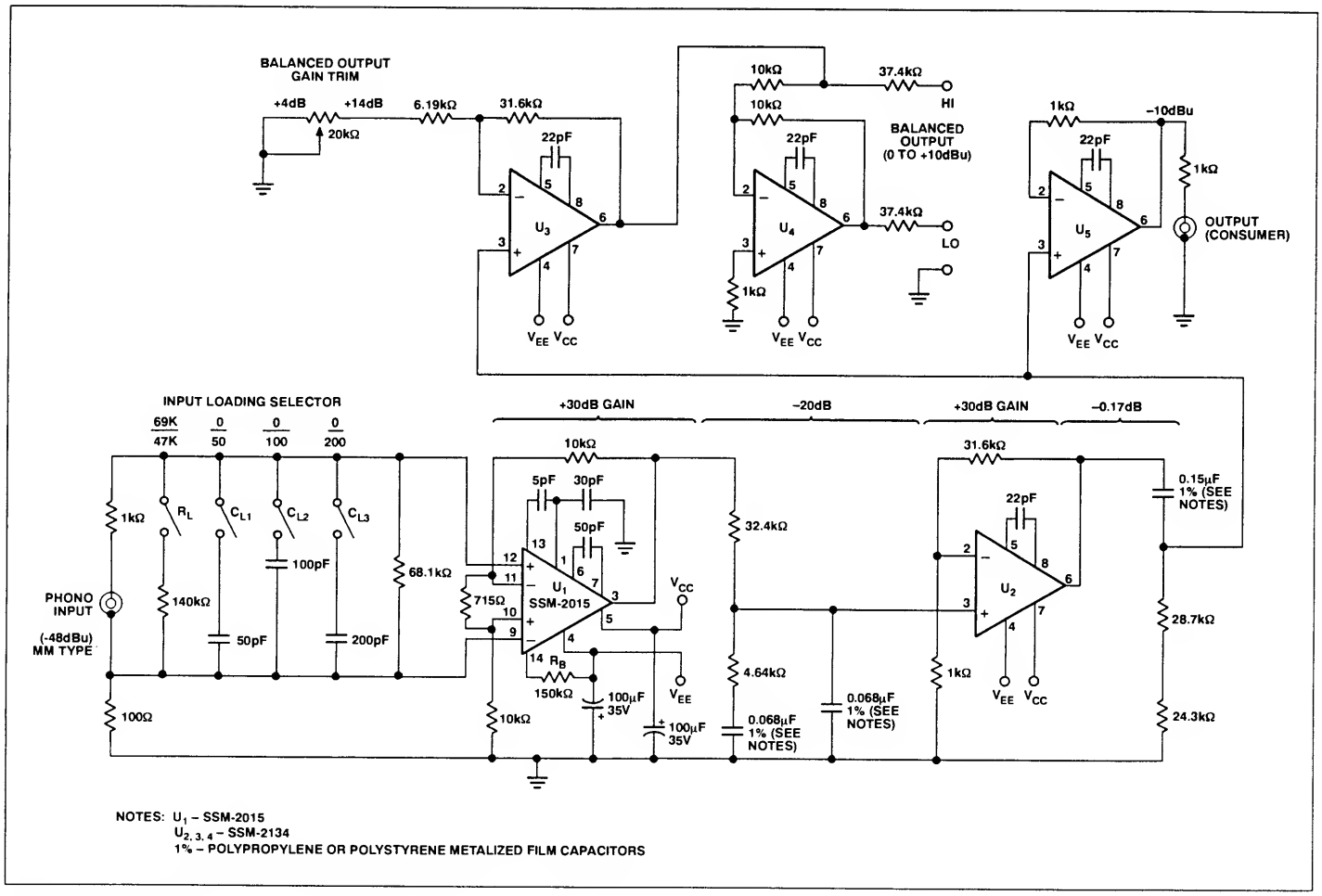


FIGURE 3: *Passive RIAA/IEC Equalized Phono Preamplifier*

The next stage contains the RIAA-RIAA/IEC equalization filter and is built around U_2, the SSM-2134 operational amplifier, and is an active feedback type filter. The overall gain of this circuit at 1,000Hz is –2.5dB. RIAA equalization requires a gain of 19.3dB at 20Hz, and attenuation of 19.6dB at 20,000Hz. The open-loop gain of U_2 is greater than 100dB at 20Hz, and 60dB at 20,000Hz, ensuring exceptional equalization accuracy.

Three filters make up the RIAA reproduction curve. The time constants are: 75µs, 318µs, and 3180µs, and a fourth time constant in the RIAA/IEC curve is 7960µs. The IEC filter was introduced to minimize warp and infrasonic signal interference while maintaining flat frequency response down to 40Hz.

- The 75µs filter is formed by resistors R_1 (9.76kΩ) and R_2 (31.8kΩ) in parallel with capacitor C_2 (0.01µF).
- The 318µs pre-emphasis filter is formed by R_2 (31.8kΩ) and C_2 (0.01µF).
- The 3180µs filter is formed by R_3 (318kΩ) and C_3 (0.01µF).
- The fourth pole, IEC 7960µs, a high pass filter is formed by R_4 (31.6kΩ) and C_4 (0.22µF), and provides 3dB attenuation at 20Hz rolling off at –6dB/octave thereafter.

Table 1 contains the complete RIAA and RIAA/IEC reproduction equalization characteristics. RIAA/IEC switching allows selection of either reproduction response curves. For the "audio purist," C_5 can be eliminated for a direct coupled design, thus reducing envelope and group delay distortions. All amplifier feedback circuits are direct coupled, and are referenced to circuit ground. The closed-loop gain is kept low to minimize input offset voltage. Therefore, only very small DC voltages can be expected at the output of the directly coupled version.

The high level amplifier, U_5, provides +12.7dB gain and feeds the unbalanced Consumer Output jack, with a nominal –10dBu level. U_5 is followed by balanced output buffer amplifier. The nominal output level is continuously adjustable from 0.0dBm to +10dBm at the balanced output terminals. The output source impedance is 75Ω, and will drive 600Ω loads to a maximum +30dBm clip point level. Table 2 shows circuit performance specifications.

TABLE 1: RIAA/IEC and RIAA Playback Characteristics

Frequency (Hz)	RIAA /IEC Relative Level (dB)	RIAA Relative Level (dB)
2.0	–0.2	
2.5	+1.8	
3.15	+3.7	
4.0	+5.7	
5.0	+7.6	
6.3	+9.4	
8.0	+11.2	
10.0	+12.8	
12.5	+14.1	
16.0	+15.4	
20.0	+16.3	+19.3
25.0	+16.8	+19.0
31.5	+17.0	+18.5
40.0	+16.8	+17.8
50.0	+16.3	+16.9
63.0	+15.4	+15.8
80.0	+14.2	+14.5
100	+12.9	+13.1
125	+11.5	+11.6
160	+9.7	+9.8
200	+8.2	+8.2
250	+6.7	+6.7
315	+5.2	+5.2
400	+3.8	+3.8
500	+2.6	+2.6
630	+0.8	+0.8
1,000	0.0	0.0
1,250	–0.8	–0.7
1,600	–1.6	–1.6
2,000	–2.6	–2.6
2,500	–3.7	–3.7
3,150	–5.0	–5.0
4,000	–6.6	–6.6
5,000	–8.2	–8.2
6,300	–10.0	–10.0
8,000	–11.9	–11.9
10,000	–13.7	–13.7
12,500	–15.6	–15.6
16,000	–17.7	–17.7
20,000	–19.6	–19.6

TABLE 2: High Accuracy Circuit Performance Specifications

MC Nominal Input Level	–64dBu (0.5mV)
MC Input Impedance	100Ω
MM Nominal Input Level	–48dBu (3.0mV)
MM Input Impedance, Resistive	69kΩ or 47kΩ
MM Input Impedance, Capacitive	50pF to 350pF
Common-Mode Rejection (20Hz to 20kHz)	>50dB
Common-Mode Voltage Limit	±10V Peak
Nominal Output Level, Balanced	+8dBu/dBm
Max Output Level, Balanced	+30dBu/dBm
Output Impedance, Balanced	70Ω
Gain Control Range, Balanced	0.0dBu to 10dBu/dBm
Nominal Output Level, Unbalanced	–10dBu
Max Output Level, Unbalanced	+24dBu
Output Impedance, Unbalanced	1,000Ω
Output Voltage Slew Rate	>6V/ μs
RIAA Reproduction Characteristics (20Hz to 20kHz)	±0.25dB
RIAA/IEC Reproduction Characteristic (2Hz to 20kHz)	±1.0dB
Wideband Frequency Response (±1.0dB)	0.0Hz to 70kHz
Signal-to-Noise Ratio (20Hz to 20kHz)	>90dB
THD + Noise (20Hz to 20kHz +8dBu, Any Output)	0.01%
IMD (SMPTE 60Hz & 4kHz, 4:1)	0.02%

A PASSIVE MULTI-FILTER DESIGN

The Passive Split Multi-Filter RIAA/IEC Preamplifier design, shown in Figure 2, is intended for moving magnet (MM) input phono transducers. The design has an extremely low noise circuit topology, high accuracy passive RIAA/IEC equalization filters, and both unbalanced consumer and balanced output circuits. The input configuration utilizes the SSM-2015. It provides the lowest possible noise, adjustable resistive and capacitive input loading, and high accuracy passive RIAA filtering totally devoid of transient and frequency dependent gain errors.

Referring to Figure 2, the following two stages contain the RIAA-RIAA/IEC passive equalization filters. All high pass and low pass filters are passive. The signal is amplified by U_2 and U_3 SSM-2134 op amps. The overall gain of the circuit at 1,000Hz is 38dB. RIAA equalization requires a gain of 19.3dB at 20Hz, and attenuation of 19.6dB at 20,000Hz. Open-loop gain of U_2 and U_3 is greater than 100dB at 20Hz, and 60dB at 20,000Hz. Closed-loop gain of U_1 is 22.5dB, and U_2, U_3 is 16.6dB, ensuring an extensive gain margin for phase accuracy. Refer to Table 3 for complete circuit specifications.

TABLE 3: Passive Multi-Filter Circuit Performance Specifications

MM Nominal Input Level	–48dBu (3.0mV)
MM Input Impedance, Resistive	69kΩ or 47kΩ
MM Input Impedance, Capacitive	50pF to 350pF
Common-Mode Rejection (20Hz to 20kHz)	> 50 dB
Common-Mode Voltage Limit	±10V Peak
Max Output Level, Balanced	+30dBu/dBm
Nominal Output Level, Balanced	+8dBu/dBm
Output Impedance, Balanced	70Ω
Gain Control Range, Balanced	0.0dBu to 10dBu/dBm
Nominal Output Level, Unbalanced	–10dBu
Max Output Level, Unbalanced	+24dBm
Output Impedance, Unbalanced	1,000Ω
Output Voltage Slew Rate	>6V/μs
RIAA Reproduction Characteristic (20Hz to 20kHz)	±0.25dB
RIAA/IEC Reproduction Characteristic (2Hz to 20kHz)	±0.5dB
Wideband Frequency Response (±1.0dB)	0.0Hz to 70kHz
Signal-to-Noise Ratio (20Hz to 20kHz)	>90dB
THD + Noise (20Hz to 20kHz +8dBu, Any Output)	0.01%
IMD (SMPTE 60Hz & 4kHz, 4:1)	0.02%

TABLE 4: Uncomplicated Passive Circuit Performance Specifications

MM Nominal Input Level	–48dBu (3.0mV)
MM Input Impedance, Resistive	69kΩ or 47kΩ
MM Input Impedance, Capacitive	50pF to 350pF
Common-Mode Rejection (20Hz to 20kHz)	> 50dB
Commom-Mode Voltage Limit	±10V Peak
Max Output Level, Balanced	+30dBu/dBm
Nominal Output Level, Balanced	+8dBu/dBm
Output Impedance, Balanced	70Ω
Gain Control Range, Balanced	0.0dBu to 10dBu/dBm
Nominal Output Level, Unbalanced	–10dBu
Max Output Level, Unbalanced	+24dBu
Output Impedance, Unbalanced	1,000Ω
Output Voltage Slew Rate	>6V/μs
RIAA Reproduction Characteristic (20Hz to 20kHz)	±0.5dB
RIAA/IEC Reproduction Characteristic (2Hz to 20kHz)	±1.0dB
Wideband Frequency Response (±1.0dB)	0.0Hz to 70kHz
Signal-to-Noise Ratio (20Hz to 20kHz)	>90dB
THD + Noise (20Hz to 20kHz, +8dBu, Any Output)	0.01%
IMD (SMPTE 60Hz & 4kHz, 4:1)	0.02%

AN ECONOMICAL APPROACH

An Uncomplicated Passive RIAA/IEC Preamplifier is shown in Figure 3. It is a low cost, practical design for a passively equalized RIAA/IEC phono preamplifier. The design shown is for moving magnet (MM) input. It also is an extremely low noise input circuit design, and includes both unbalanced consumer and balanced output circuit configurations. The input circuit also utilizes the SSM-2015, and provides adjustable resistive and capacitive input loading. Wide bandwidth stages minimize in-band phase shift, and provide exceptional phase and frequency response accuracy. Table 4 details circuit performance data.

SUMMARY

For a phono transducer cartridge to deliver the performance as intended, it should be loaded with proper resistance and capacitance. The MM input circuits have adjustable transducer loading. Most transducers currently available will be accommodated with resistive loading of 69kΩ or 47kΩ, and capacitive loading of a few pF (input wiring dependent) to 350pF, in 50pF steps.

If greater input common-mode noise rejection is required, it can be obtained in all input designs by increasing the value of the 100Ω resistor and 0.1μF capacitor connected between the input RCA jack shield connection and the main circuit ground point. The values shown satisfy most requirements for 1 meter cables supplied with the newer tone arms.

All circuits described are signal noninverting, and constructed with bipolar IC amplifiers for lowest noise. They are compensated for widest bandwidth and circuit stability.

To achieve optimum trouble-free performance, a few construction and manufacturing tips should be observed. For grounding to be truly effective, all grounded components must return to a single point. This technique is effective in minimizing ground current loops that can cause excessive noise, signal cross-talk, AC power line noise, and circuit instability, and permit external noise spikes to enter. The ground center should be as close to the input amplifier (U_1) as possible. All grounded components of U_2, U_3, U_4, U_5, the output jack grounds, and the power supply ground lead should be tied to the same U_1 ground point.

As long as the power supply leads are kept short, and adequately filtered and bypassed with polyester film capacitor at the regulators, there is no need for individual decoupling capacitors at U_2, U_3, U_4, and U_5. The power supply voltages should be regulated for $\pm 18V_{DC}$.

All signal filter components should be of the highest quality, i.e., metalized polypropylene or polystyrene film, 1% tolerance capacitors (except for C_5, 5% tolerance is OK) and metal film resistors, 1% or better tolerance.